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The Arc-Second Alignment of Sun-Seeking Optical Detectors

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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Frank J. Bane

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Contracts Management Office

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The CRLS-229 Solar X-ray Spectrometer/Spectroheliograph experiment to be flown on the USAF Space Test Program (STP) P78-1 satellite uses crossed Refractosyn sun detectors to verify the satellite solar pointing. A technique utilizing solar radiation was devised to find the relationship between each detector's null axis and the normal to its flat front surface. The front surface is then used, with an autocollimator, to align the detectors to the experiment view axis. This report describes the alignment procedure and alignment tests performed with the payload installed in the spacecraft.

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FIGURES

I. Introduction

The CRLS-229 experiment on the USAF Space Test Program P78-1 satellite is a complex collection of solar X-ray instruments. Each of the two Aerospace Corporation SOLEX spectrometer/spectroheliograph instruments is equipped with a multigrid collimator to confine the field of view to 60 arc seconds in one case and 20 arc seconds in the other. The Naval Research Laboratory MAGMAP magnesium line mapping experiment also uses the 60 second SOLEX collimator. The satellite is equipped with a solar rastering and pointing assembly to point these and other experiments at selected solar observation targets. This pointing system is controlled and the pointing coordinates are read out by sensors mounted on the outside of the CRLS-229 experiment and coaligned with the collimators. Small, simple sun sensors were mounted on the CRLS-229 20 arc second collimator to provide independent verification of the pointing system performance and of the continued alignment of the SOLEX experiment with the pointing system sensors on orbit. The alignment of the CRLS-229 sun sensors is the subject of this report.

The CRLS-229 "boresight" sensors chosen were Refractosyns*, manufactured by H. H. Controls Co., Inc. These devices combine simplicity and accuracy of operation with small size (1.3 cm diameter by 2.2 cm high, 5 gm) and are ideal for our application. Figure 1 is a simplified drawing of the detector and will be referred to in the following discussion of the Refractosyn operation. The prism is an isosceles triangle with base angles equal to θ_c, the critical angle for total internal reflection for radiation to which the photodetectors are sensitive. Thus radiation incident along a certain direction, called the detector null axis, strikes each side of the triangle at the critical angle, and

*H. H. Controls Co., Inc., U.S. Patent No. 3,137,794.

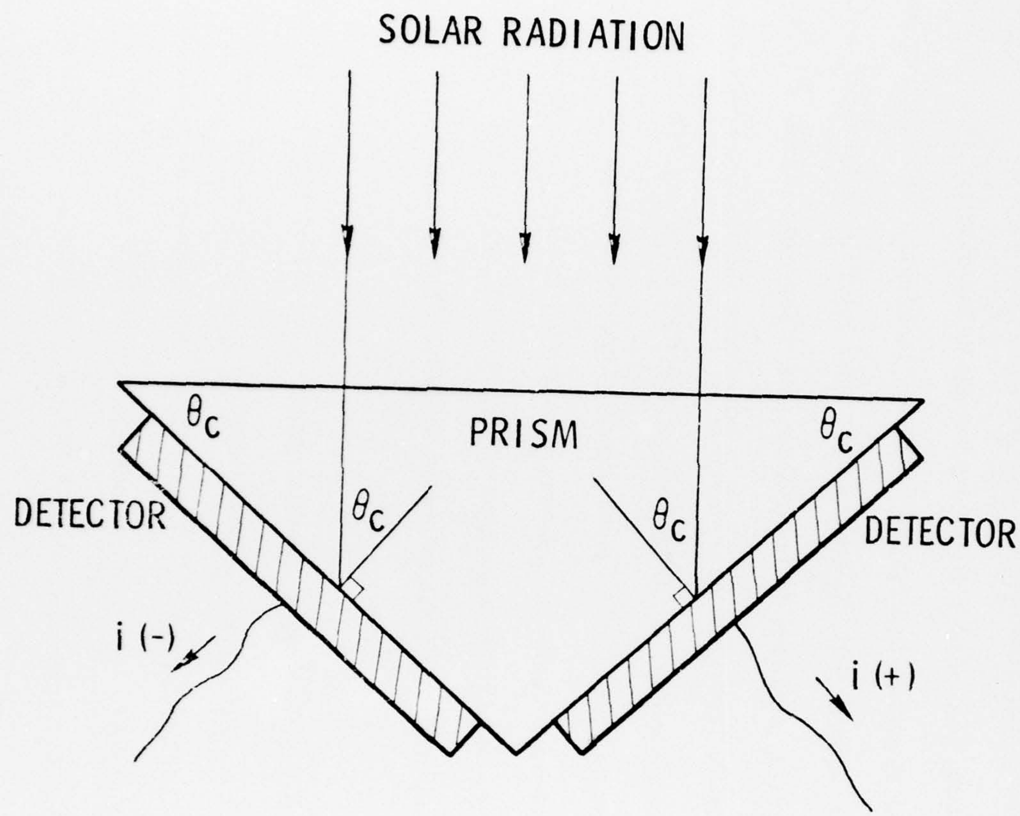

Figure 1: A diagram indicating the operating principles of the Refractosyn sun finder.

no radiation is detected. Note that even if the base angles differ from θ_c, the device will still have a null detection axis as long as the apex angle is $180^{\circ}-2\theta_c$. Since the sun has a finite extent (32 arc min) solar radiation will be incident in a range of angles. The sensitivities of the detectors are balanced so that the system still has a null axis. Radiation off-axis but in the plane of the figure will give a net positive or negative current. If the sun is out of the plane of the figure a null will occur and will broaden as the source's angular distance from the plane increases.

In the CRLS-229 experiment, two Refractosyns, set at right angles to one another, are used to locate the center of the sun. Each detector has associated circuitry that operates as a current discriminator. A single telemetry bit reads out a one when the absolute value of the net current is below a threshold value and a zero when the current exceeds the threshold. Thus the two boresight bits are both ones only when the collimator is pointed within about one arc minute of sun center, or when the sun is not within the field of view.

II. Alignment

Alignment of the boresight eyes (Refractosyns) with the SOLEX collimator axis presents a problem. In its assembly, each collimator is provided with a reference mirror which is adjusted so that its normal coincides with the collimator X-ray axis. The boresight detectors were coaligned by comparing their normals to the normal to the 20 arc second collimator mirror, using a two-axis measuring autocollimator. As we have noted above, the Refractosyn normal need not correspond to its null axis, so the relationship between the axis and the front surface normal must be discovered. The major part of the alignment procedure is aimed at finding this relationship.

In order to describe the alignment measurement we need to specify a coordinate system. Since the measurement is made using an equatorial mount we will use this system as the basis for the coordinate system. Thus the z axis is parallel to the Earth's rotation axis and +z is north. The y axis is perpendicular to the z axis and coplanar with the vector from the center of the Earth to the sun. The +y axis points away from the Earth. The x-axis is defined to complete a right handed coordinate system. Thus at local noon +x is west.

Figure 2 shows the mounting fixture for the test. A large bracket holds an optical flat in place using nylon screws. The detector under test is clamped into its fixture and retained by tightening the clamping mechanism. Two slotted screws, locked by nuts as shown, bear on the optical flat. Thus the angle of the test detector with respect to the reference detector, also shown, may be adjusted by turning either of the slotted adjustment screws. The entire assembly is clamped to a shaft that forms the x axis of an equatorial mount, and a large screw is tightened to clamp the assembly to the shaft.

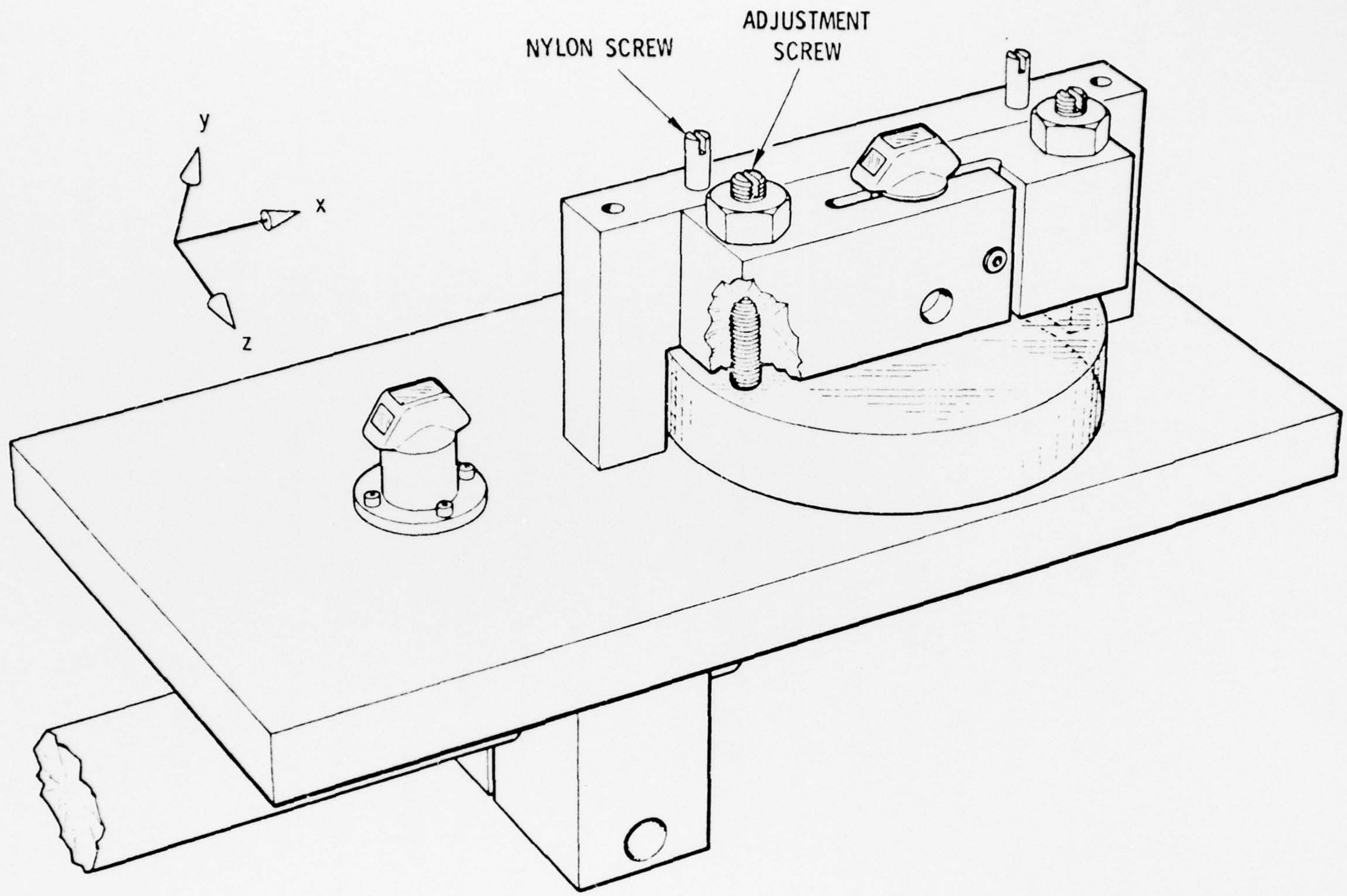

Figure 2: The experimental set-up for the coalignment of the sun finder null axis with the normal to an optical flat.

The measurement is made by first connecting each detector's leads and a load resistor across the input terminals of one channel of a two-channel strip chart recorder. Thus when a detector's axis is pointed off sun center (but near the sun) a current flows and a voltage appears across the chart recorder input terminals. The assembly is rotated about the z axis of the equatorial mount until the detector axes are both just "ahead" of the sun. The sun then transits, and the delay, t_A, between the null for the test detector and that for the reference detector is measured. It is easy to set the equatorial mount so that this measurement can be accomplished in about one minute. The test detector fixture is then removed, rotated end to end, and replaced on the flat, and the measurement is repeated to find a second delay, t_B. If t_A equals t_B the test is terminated; if not, one of the slotted screws is adjusted and another pair of measurements is made. When t_A equals t_B the test detector null axis is parallel to the optical flat normal. This procedure, resulting in the coalignment of the test detector null axis and the optical flat normal to an accuracy of a few arc seconds, takes less than half an hour. The relationship between the detector's *front surface normal* and its null axis may then be found by comparing the front surface normal to the optical flat normal.

The adjustment process can be simplified by an easy calculation of the amount by which the adjustment screw must be turned to reduce $t_D = (t_A - t_B)/2$ to zero. We define ω_x as the x component of the angular velocity of the sun in its apparent motion across the sky:

$$\omega_x = \Omega \cos \delta_s , \tag{1}$$

where Ω is the angular velocity of the Earth's rotation and δ_s is the declination of the sun. The deviation of the detector axis from the optical flat normal, projected on the xy plane is $\omega_x t_D$. If the separation of the screws is D then one screw must be moved in or out by an amount ϵ, where

$$\epsilon = D \Omega t_D \cos \delta_s . \tag{2}$$

Since the pitch of the screw is known, the angle, ϕ, through which the screw must be turned can be quickly calculated. In particular, for the 1/4 x 28 screws we used we have the simple relationship

$$\phi(\text{degrees}) \approx 10^4 \epsilon \approx 10^4 D \Omega t_D \cos \delta_s , \tag{3}$$

if D is measured in inches, t_D in seconds, and Ω in radians per second.

As we mentioned above, the result of the foregoing measurement process is that the deviation between the Refractosyn axis and the optical flat normal, when projected on the xy plane, is zero. To find the xy plane projection of the deviation of the detector's axis from its front surface normal we use a measuring autocollimator with the test assembly mounted on a precision rotating table which is also adjustable in elevation. Because of the small size of the Refractosyn, its glass front surface does not reflect enough light for it to be detectable by the autocollimator. Therefore the entire detector fixture must be carefully removed and put into a vacuum chamber where aluminum is deposited on the front surface of the detector. The fixture is then carefully replaced on the optical flat and the autocollimator measurement made. The return image from the

detector is centered on the autocollimator cross hairs then the necessary adjustments in elevation and azimuth are made to center the optical flat's return image. Azimuthal adjustments of both the table and the autocollimator are made, and the xy projection of the difference between the detector normal and its null axis (the flat's normal) is the algebraic sum of the table and autocollimator adjustments. Care must be taken to note the detector orientation and the direction of the axis-front normal deviation. We carried out the foregoing measurement process on four detectors and found deviations of 7'22", 8'56", 3'16", and 3'46".

III. Test Results

Using the results of the foregoing tests, we aligned the Refractosyn null axes to the 20 arc second collimator reference mirror with an autocollimator. After the collimator was installed in the instrument and the alignment rechecked, the aluminum on the front surface of the Refractosyns was removed with a solution of NaOH. The CRLS-229 experiment was then installed in the spacecraft and the spacecraft solar eyes aligned with the collimator reference mirrors.

The P78-1 satellite was operated in the Ball Aerospace Systems Divison clean room/solarium to test the spacecraft's solar pointing and rastering functions. As part of this test the CRLS-229 boresight detector bits were read out while the pointed instrument assembly was rastered over the sun. As expected, both detectors read out ones only while the assembly was pointed to a small region near the center of the sun. This region was offset from sun center by about 90 arc seconds in one direction and by less than or equal about 20 arc seconds in the other. The process by which the boresight detectors are aligned to the spacecraft control eye is complicated and involves a number of steps and optical transfers, but an error of 90 arc seconds is unexpectedly large, and is at present unexplained. The spacecraft underwent acoustic testing between the payload installation and alignment and the sun tests, and it is possible that the detector shifted at this time. This cannot be checked with an autocollimator because of the small size and low reflectivity of the Refractosyn front surface. No other measurable component of the CRLS-229 payload underwent a shift of more than a few arc seconds in acoustic testing. The other error of less than or equal 20 arc seconds is not unexpected and is entirely acceptable, as the original aim was to verify the pointing to an accuracy of around one arc minute.

IV. Conclusions

The CRLS-229 instrument requires a simple means of verifying the accuracy of the P78-1 spacecraft sun pointing system and the SOLEX and MAGMAP experiments' continued alignment with the spacecraft's pointing sensors on orbit. A system of two crossed Refractosyn sun detectors satisfies this requirement with minimal size, weight, and telemetry demands. A ground-based alignment technique using solar radiation has been developed for these detectors. An accuracy of a few arc seconds can be achieved. Tests with the experiment in the spacecraft show that one of the flight sensors maintained its alignment to 20 arc seconds or better through spacecraft testing and that the other's alignment is currently off by about 90 seconds of arc. The origin of the error in the second case is currently unknown.

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